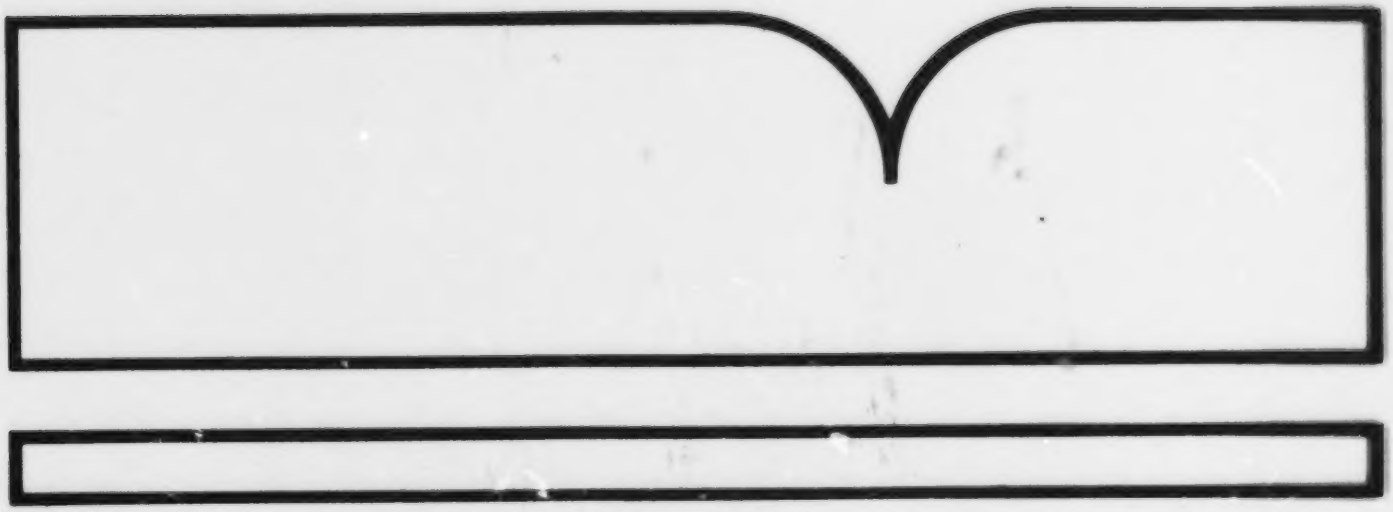
PB84-130483

Green River Ambient Model Assessment Program

(U.S.) Environmental Sciences Research Lab.
Research Triangle Park, NC

1983



U.S. Department of Commerce
National Technical Information Service
NTIS

PB84-130483

EPA-600/D-84-027
1983

THE GREEN RIVER AMBIENT MODEL ASSESSMENT PROGRAM

by

Francis A. Schiermeier* and Alan H. Huber*
Environmental Sciences Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

C. David Whiteman and K. Jerry Allwine
Pacific Northwest Laboratory
Richland, WA 99352

ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

*On assignment from National Oceanic and Atmospheric Administration

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/D-84-027		PB84 130483

4. TITLE AND SUBTITLE	5. REPORT DATE
THE GREEN RIVER AMBIENT MODEL ASSESSMENT PROGRAM	1983
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
F. A. Schiermeier, A. H. Huber, C. D. Whiteman, and K. J. Allwine	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
(Same as box 12)	CDTA1D/09-3062 (FY-83)
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Environmental Sciences Research Laboratory-RTP, NC Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, North Carolina 27711	Interim 6/80-6/83
	14. SPONSORING AGENCY CODE EPA/600/09

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Due to the proposed development of the Green River Oil Shale Formation encompassing the areas of southwestern Wyoming, northeastern Utah, and northwestern Colorado, the EPA Region VIII Headquarters in Denver has a specific need for the development of site-specific ambient dispersion models. To meet this requirement, the Green River Ambient Model Assessmentt (GRAMA) project was initiated to develop improved air quality models for analyzing the impacts of the oil shale industry with respect to PSD increments over pristine wilderness areas, and ambient air quality standards for criteria pollutants.

Two air quality simulation models are currently under development for this complex region. One model, VALMET, is a local-scale model for predicting concentrations of nonreactive pollutants within a well-defined mountain valley configuration. The second model, MELSAR, is a mesoscale Lagrangian puff model for predicting pollutant concentrations within a 500 km by 450 km region. This paper gives a description of the current VALMET model followed by brief explanations of the MELSAR model and the GRAMA field experiments. The paper concludes with a summary of the GRAMA project.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	19
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Presented at NATO/CCMS 14th International Technical Meeting on Air Pollution Modeling and Its Applications, Copenhagen, Denmark, September 27-30, 1983.

THE GREEN RIVER AMBIENT MODEL ASSESSMENT PROGRAM

Francis A. Schiermeier* and Alan H. Huber*

U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

C. David Whiteman and K. Jerry Allwine

Pacific Northwest Laboratory
Richland, Washington 99352

INTRODUCTION

The Clean Air Act Amendment of 1977 requires the U.S. Environmental Protection Agency (EPA) to promulgate regulations that specify the use of atmospheric dispersion models to achieve air quality limits pertinent to Prevention of Significant Deterioration (PSD) and attainment of National Ambient Air Quality Standards (NAAQS). A major need exists for predictive models of pollutant transport and diffusion in complex terrain, especially in the pristine areas of western United States where energy development and utilization are rapidly expanding.

Due to the proposed development of the Green River Oil Shale Formation encompassing the areas of southwestern Wyoming, northeastern Utah and northwestern Colorado (Figure 1), the EPA Region VIII Headquarters in Denver has a specific need for the development of site-specific ambient dispersion models. To meet this requirement, the Environmental Sciences Research Laboratory has inititated the Green River Ambient Model Assessment (GRAMA) program. The main objective of this program is to develop improved air quality models for analyzing the impacts of the oil shale industry with respect to PSD increments over pristine wilderness areas and to ambient air quality standards for criteria pollutants. The GRAMA program is being conducted under an Interagency Agreement by the Pacific Northwest Laboratory (PNL), operated for the U.S. Department of Energy by Battelle Memorial Institute.

*On assignment from National Oceanic and Atmospheric Administration

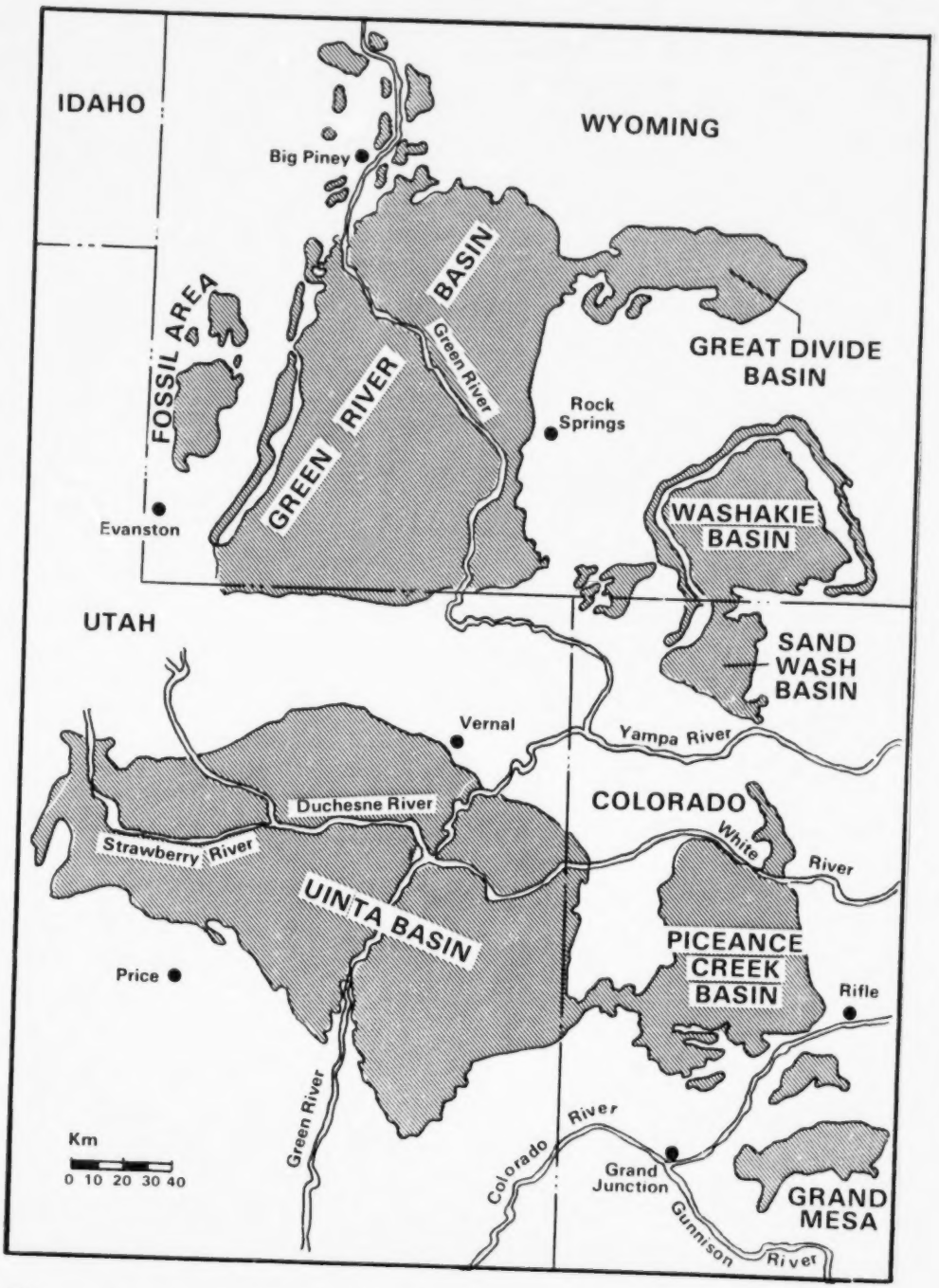


Figure 1. Green River Oil Shale Formation areas (shaded) of western United States.

Two air quality simulation models are currently being developed by PNL for this topographically and meteorologically complex region. Both are designed in a modular structure so that additional modules may subsequently be incorporated without significantly affecting the overall code framework. One model, VALMET, is a local-scale model for predicting concentrations of nonreactive pollutants within a well-defined mountain valley configuration. The current version of VALMET has not yet undergone sensitivity tests, has not been evaluated with respect to its performance in simulating air pollution concentrations in actual valleys, and contains modules that are not yet fully developed. A tracer experiment was conducted recently in a deep mountain valley in Colorado to provide data for preliminary evaluation of VALMET.

The second model, MELSAR, is a mesoscale Lagrangian puff model for predicting pollutant concentrations within a 500 km by 450 km region. This model is currently in the developmental stage, although a preliminary version is operational which computes short-term (up to 24-hour) pollutant concentrations at specified receptors. The computer code has not been fully tested and several program modules are incomplete.

This paper gives a description of the current VALMET model followed by brief explanations of the MELSAR model and the GRAMA field experiments. The paper concludes with a summary of the GRAMA program.

VALMET MODEL DEVELOPMENT

The VALMET (VALley METeorology) air quality model was developed to predict concentrations of a nonreactive pollutant arising from an elevated continuous point source located within a well-defined mountain valley. The pollutant concentrations are computed at the valley floor and sidewalls on a valley cross section a selected distance downwind from the pollutant source. The model is intended to simulate the effects on pollutant transport and diffusion of various meteorological processes that are thought to result in worst-case pollutant concentrations. The model is designed for situations in which pollutants are carried in locally developed circulations within a valley when these circulations are decoupled from prevailing regional flow above the valley. Detailed descriptions of the meteorological hypotheses on which VALMET is based and of the model itself are given by Whiteman and Allwine (1983a).

The VALMET model, while including a variety of meteorological processes, is highly parameterized so it is simple in

concept and easy to run. VALMET is composed of 13 modules, or subroutines, arranged so that an improved understanding of individual valley meteorological phenomena can be easily incorporated into future versions. The modules can be replaced by measurement data if such are available. Thus, the model can be used in either of two modes. It can be used in a screening mode to calculate pollutant concentrations within a valley when little site-specific data are available or it can be used as a site-specific model by calibrating it with actual measurement data.

VALMET was developed primarily to predict pollutant concentrations during the post-sunrise temperature inversion breakup period. However, the air pollution concentrations within the valley cross section at sunrise must be known for the post-sunrise simulation. VALMET is therefore comprised of two parts--a nighttime part to predict concentrations on the valley cross section at sunrise, and a daytime part to predict concentrations on the valley floor and sidewalls during the post-sunrise temperature inversion breakup period.

VALMET Nocturnal Component

Steady-state nocturnal pollutant concentrations within a valley cross section are determined by a Gaussian plume model that is modified to account for channeling and reflections off the sidewalls within the valley, for dilution due to clean air volume flux convergence within the valley, and for diffusion of pollutants out the top of the valley inversion. The model begins with an elevated pollutant source located anywhere on the valley floor. (The present version of the model cannot handle sources on the valley sidewalls.) The source is assumed to emit a continuous elevated pollutant plume into a nocturnal valley temperature inversion. A plume rise formulation simulates the initial rise of the pollutant plume at the stack due to momentum and buoyancy of the effluent.

Nocturnal dispersion coefficients for the Gaussian plume equations are determined from the empirically derived Pasquill-Gifford curves, which were developed from atmospheric tracer experiments conducted over homogeneous terrain for various downwind distances and stability categories. Because of the enhanced nocturnal diffusion in the rough valley terrain, the valley dispersion coefficients are derived from the original Pasquill-Gifford curves by simply adjusting the stability categories. From existing data, it appears that the enhancement of horizontal dispersion can be approximated by dropping the

stability two categories (e.g., F becomes D), and the enhancement of vertical dispersion can be estimated by dropping the stability one category (e.g., F becomes E). These simple adjustments to the stability categories are a temporary measure until more appropriate means are developed for handling nocturnal dispersion in deep valley terrain.

Dispersion of pollutants during the plume's nocturnal transport down the valley will cause a spreading of the plume in both the vertical and horizontal, resulting in the plume's eventual contact with the valley floor and sidewalls. Additional spreading of the plume, using the basic Gaussian equations, would result in physically unrealistic concentrations occurring "beyond" the valley sidewalls or "below" the valley floor. This was handled by superimposing the valley cross section on the theoretical plume cross section and, through integrations, determining the fraction of pollutant mass within the valley below the inversion top, as well as the mass that has diffused above the inversion top and beyond the valley sidewalls and valley floor. To conserve pollutant mass within the valley, the mass fraction that has diffused "beyond" the valley sidewalls and "below" the valley floor is folded back into the valley cross section, assuming uniform mixing within the cross section.

Calculations with the Gaussian plume model are made assuming the Gaussian plume is channeled down the valley axis, despite meanders in the valley's course (Figure 2). The down-valley distance of a given cross section must therefore be determined from topographic charts to account for such valley axis meander.

An important factor affecting plume concentrations is the dilution of the plume during its travel down a valley due to tributary flows that bring clean air into the plume. Other processes occurring in valleys that affect plume dilution include converging downslope drainage flows and entrainment of clean air into a valley from above. Any process capable of producing volume flux convergence between two vertical valley cross sections is capable of diluting a plume. At present, the physical understanding of these processes is insufficient to incorporate them explicitly into an air quality model. The extent to which volume flux convergence is a feature of a particular valley's meteorology can be determined, however, by wind observations.

In the present version of VALMET, the Gaussian plume equation is modified initially to correct for the dilution of a pollutant plume during its down-valley travel. The correction is applied to the plume-transporting wind speed at the pollution source cross section to obtain a modified or virtual wind

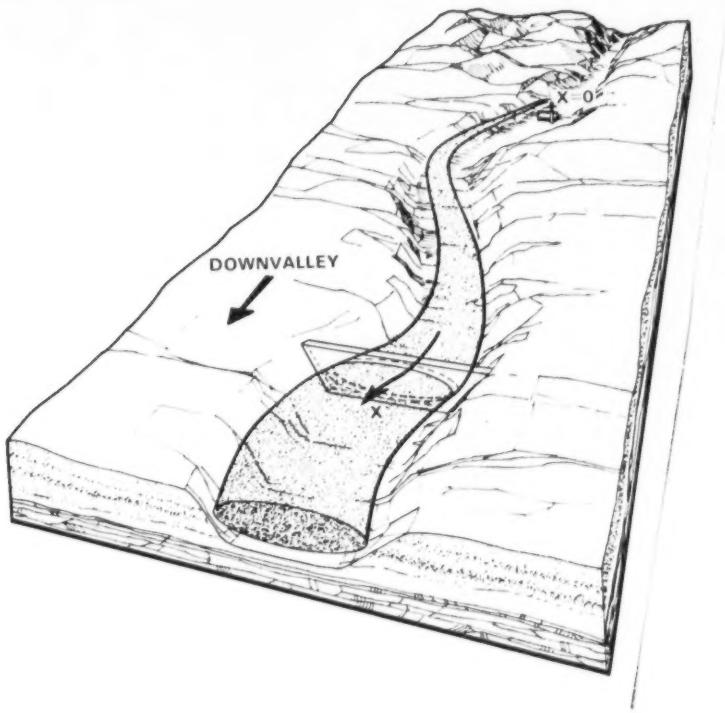


Figure 2. Illustration of the nocturnal down-valley transport and diffusion of a pollutant plume as related to terrain-following coordinate system.

speed u_v. The virtual wind speed is a function of the ratio of the volume fluxes across the source and receptor cross sections. The value of u_v is substituted for u_s (actual wind speed) in the denominator of the Gaussian plume equation to calculate pollutant concentrations at the receptor cross section. To avoid physically unrealistic results, u_v must always be equal to or greater than u_s.

VALMET Daytime Component

The daytime simulation uses numerical techniques that simulate the fumigation of the nocturnal plume onto the valley floor and sidewalls as a convective boundary layer grows upward from the heated valley surfaces and as subsiding motions occur over the valley center after sunrise. This daytime portion of VALMET begins with solar radiation calculations, parameterization of the surface energy budget, and estimation of the temporal

variation of sensible heat flux which destroys the temperature inversion after sunrise. The valley energy budget model of Whiteman and McKee (1982) is invoked to simulate convective boundary layer (CBL) growth and inversion descent. The nighttime Gaussian plume on a valley cross section is used as the initial condition from which the numerical model calculates concentrations in grid elements that are fixed to the valley floor and sidewalls (Figure 3). The depth of these vertically growing grid elements is identified with the CBL height. Calculations are made of concentrations within the grid elements taking account of fumigation of the Gaussian plume into the elements and upslope advection from grid element to grid element. Pollutants are mixed uniformly within each grid element, roughly simulating atmospheric diffusion processes in the convective boundary layer.

This daytime model is driven by sensible heat flux, estimated as a fraction of the solar radiation using a highly parameterized surface energy budget. Equations were derived to determine extraterrestrial solar flux at any site and for any given time. The sensible heat flux was parameterized as a constant fraction of the time-dependent extraterrestrial solar flux. The effects of such factors as snow cover, soil moisture, cloud cover, or surface albedo are not explicitly included in the daytime model, but can be incorporated through an expanded energy budget module, using as a basis the extensive work already conducted on these topics by other investigators.

The daytime component of VALMET uses a numerical technique to simulate time-varying pollutant concentrations in the grid elements fixed to the valley floor and sidewalls. Grid elements are arrayed from the valley center across the valley floor and up the sidewall, with grid element height representing the height of the CBL, assumed not to vary from grid element to grid element. At sunrise, the model is initiated with a shallow CBL height and an inversion top height obtained from observations in the modeled valley.

The atmospheric energy budget approach used by Whiteman and McKee (1982) is capable of partitioning energy between these two different processes to produce inversion destruction solely by CBL growth, solely by inversion descent (assuming a non-growing CBL is present initially in a simulation), or by a combination of the two processes. The partitioning is controlled by a single parameter defined as the fraction of sensible heat flux going to CBL growth. The remaining fraction is assumed to be responsible for mass transport up the sidewalls, which results in inversion descent. The proper partitioning of energy in a particular valley can be determined by fitting the thermodynamic model to observations from the valley.

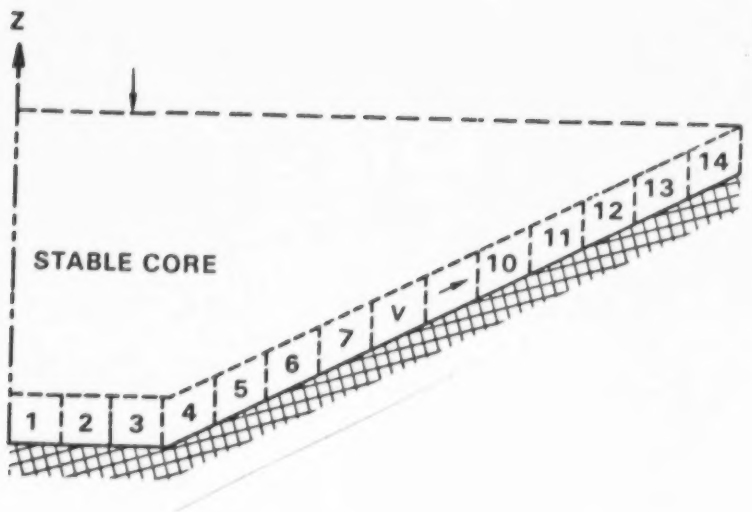


Figure 3. Cross section of the valley floor and sidewalls illustrating the grid elements whose heights correspond to the CBL height. The rate of sinking of the inversion top (vertical arrow) is related to the upslope transport of mass (diagonal arrow) by the equation of mass continuity.

Daytime pollutant concentrations are computed by treating the Gaussian plume within the cross section as being "frozen" within the inversion. After sunrise, concentrations within individual grid elements change as the grid elements grow upwards into the frozen plume, as the inversion sinks causing pollutants to sink into the tops of the grid elements, and as upslope flows develop within the CBL. These slope flows arise as air parcels are heated by sensible heat flux over the sidewalls and rise up the slope. The speeds of the slope flows are calculated under a continuity of mass constraint within the cross section below the (sinking) inversion top. That is, sinking of the top of the inversion with time implies that mass is removed from the cross section below the inversion top level.

Pollution concentrations are calculated for each time step for each grid element following the general outlines of a numerical method described by Whiteman and McKee (1977). Calculations at each time step are performed sequentially for all of the grid elements, beginning with the grid element at the valley center and progressing up the valley sidewall. Calculations

within each grid element are made assuming pollutant mass conservation. The pollutant mass sinking into the top of each growing grid element and the pollutant mass advected into and out of each grid element is computed using the velocity calculations at grid element septa as determined using a total air mass conservation constraint.

VALMET uses a continuity equation for air of constant density to calculate wind velocities at the boundaries or septa of the grid elements in the slope flow layer. Assuming the wind velocity on the left septum at the valley center is zero (i.e., there is no mass transferred across the valley center within the CBL), a sinking inversion will produce a wind speed increase from the left septum to the right septum of the grid element (Figure 3). The velocity normal to a given septum of any grid element can thus be determined by summing the velocity changes calculated across each grid element beginning at the valley center and ending at the septum of interest.

A modification to the pollutant calculation procedure is necessary for individual grid elements on the sidewalls when the top of the inversion descends below the level of the grid element. The grid element depth, defined as the depth of the CBL, suddenly increases when this occurs, necessitating a rapid decrease in grid concentrations. This is handled in VALMET by simply allowing the last concentration calculated in the grid element to decay exponentially with time after the inversion top descends below the grid element. Because observational evidence is lacking, the time constant of the exponential decay is chosen arbitrarily so that the concentration decreases by 2% at each subsequent time step.

The criteria for maintaining numerical stability constrain the model user to maintain a certain relationship between the model time step and the grid element crosswind length, depending on the upslope wind speeds encountered in the simulation. The maximum upslope wind speed simulation in the model, when multiplied by the time step length, must be less than the grid element length to maintain computational stability. These constraints are performed automatically within VALMET.

Pollutant concentrations may be calculated for every time step for every grid element. Rather than storing each of these concentrations, which would require a large amount of memory, 5-min average concentrations are stored and constitute one of the major VALMET outputs. Additional outputs are the maximum 1- and 3-hour average concentrations and their times of occurrence in each of the grid elements. These calculations are made from the

basic 5-min average concentration array for each grid element by means of a moving average method.

The results of a model run are written to two output disk files. The first output file is a formatted file which contains the results of the model run. After the model is run, the contents of this file may be printed to obtain a summary record of the model run, including model input parameters and outputs. A second file is also automatically generated with every computer run. This formatted file contains time series of pollutant concentrations, temperature inversion depths, and convective boundary layer depths, as well as many of the basic parameters used in the model run. This file is created for the user who wishes to develop his own programs to plot the results of a model run.

Following is a sample simulation by Whiteman and Allwine (1983b) for a 600 m wide valley with 15 degree sidewalls. The valley inversion at sunrise is assumed to be 500 m deep with an average potential temperature gradient of 25°K per km. The pollution source emits a non-reactive pollutant at the rate of 1 g/s at a height of 250 m after plume rise into a 4 m/s down-valley wind on September 21 at latitude 40°N and longitude 105°W. The model time step is 10 s, and the grid elements are 100 m long. The sensible heat flux is 24% of the solar heat flux, and 15% of the sensible heat flux is used to increase CBL height. The remaining 85% is used to transport mass up the sidewalls. The simulation for a downvalley distance of 10 km from the source is shown in Figure 4 as concentration plots for grid elements 03, 06, 09, 12, and 15 between 0500 and 1100 LST.

Low and steady nocturnal concentrations are initially observed at the 10-km down-valley distance in all grid elements since diffusion from the centerline is not yet sufficient to produce large concentrations on the valley floor or sidewalls. The plume centerline concentration 250 m above the valley floor is 1.19 $\mu g/m^3$. Only 0.1% of the plume has diffused out the top of the valley. After sunrise (just before 0600), fumigation and upslope advection begin, raising concentrations on the sidewalls and valley floor. The highest concentrations due to fumigation occur over the center of the valley floor just before 0900. Here, the highest one-hour average concentration of 0.70 $\mu g/m^3$ occurs. Concentrations in the highest grid elements on the sidewalls are relatively low, although upslope flows carry up the higher concentrations observed first on the lower slopes. Diffusion in the growing CBL occurs during this transport. Concentrations drop to zero rapidly in the sidewall grid elements as the top of the temperature inversion sinks below their elevations

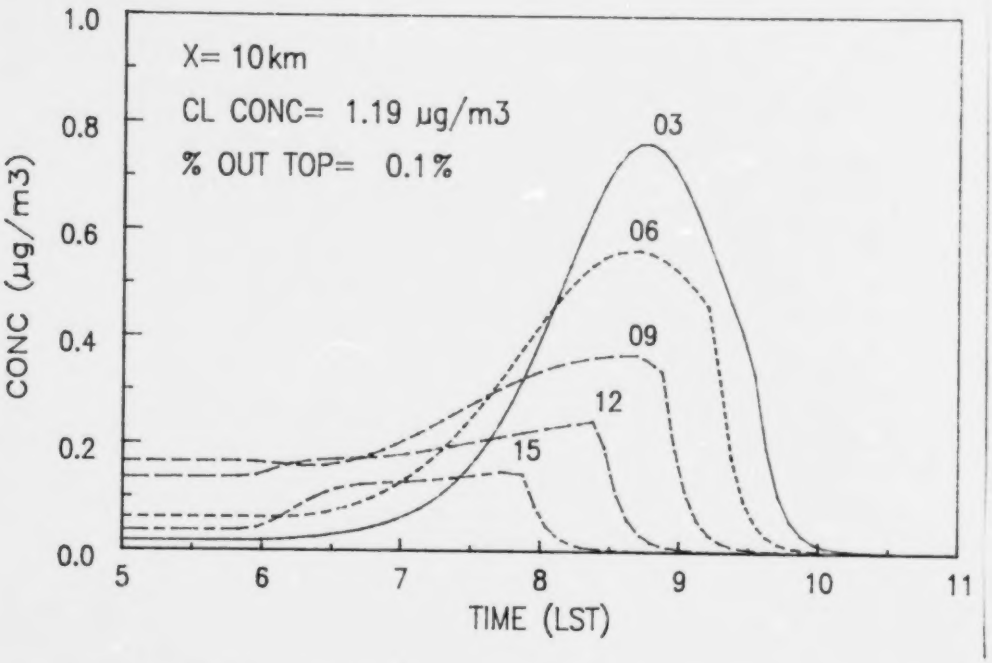


Figure 4. VALMET pollutant concentration versus time for selected grid elements. In the legend, X is down-valley distance, CL CONC is centerline concentration, and % OUT TOP is the fraction of mass diffusing out the top of the valley inversion during the plume's nocturnal transport.

and the mixing layer suddenly becomes unlimited. The concentration in Box 03, the last valley floor grid element, drops to zero at the time of temperature inversion destruction (ca. 0940).

MELSAR MODEL DEVELOPMENT

A preliminary version of a puff trajectory air quality model has been developed by PNL to simulate air pollutant transport and diffusion over a specific region 500 km in the east-west direction by 450 km in the north-south direction. This region covers the mountainous areas of western Colorado, eastern Utah and southern Wyoming as shown in Figure 5. The modeling system called MELSAR (MEsoscale Location Specific Air Resources model) currently consists of four programming components: a terrain processor; a meteorological data processor; a pollutant transport, diffusion and concentration computing module; and a post-processor. MELSAR is to be used principally for estimating short-term (3-hour and 24-hour) SO_2 and Total Suspended

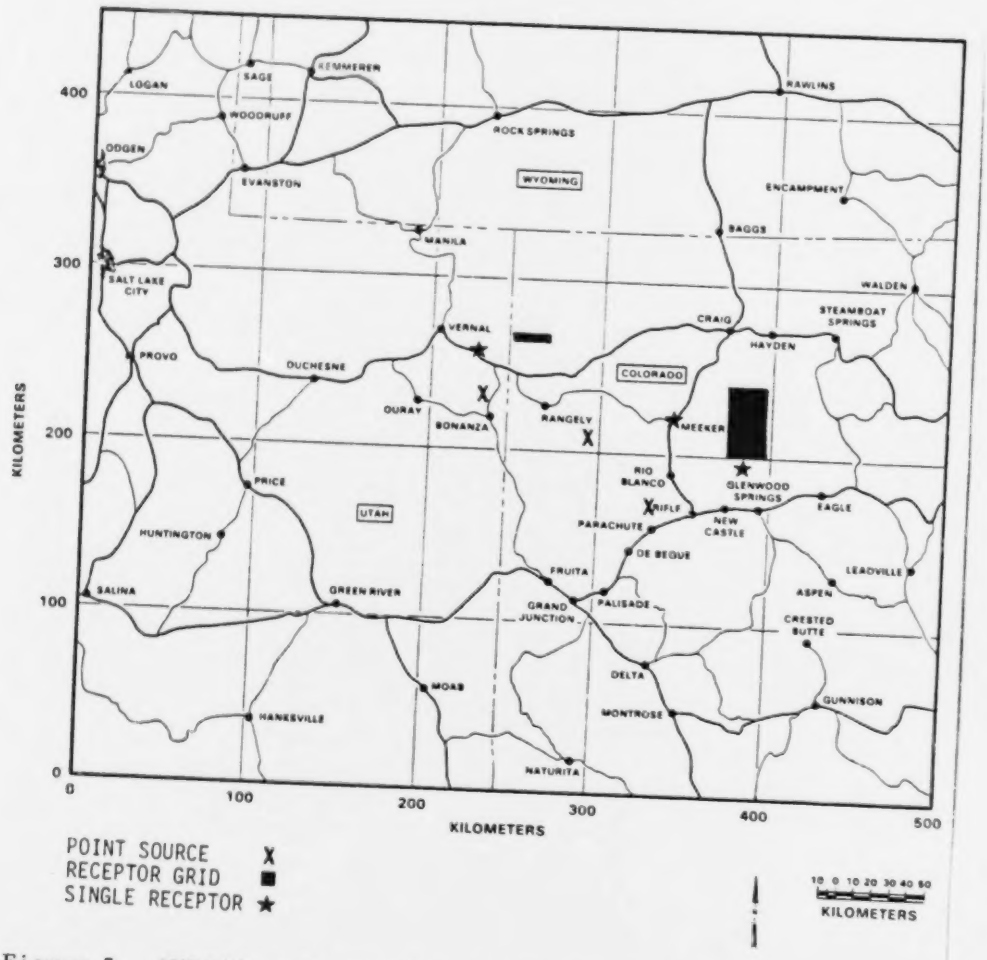


Figure 5. MELSAR air quality model domain with hypothetical locations of point sources and receptors for illustration.

Particulate (TSP) average air concentrations in determining compliance with PSD regulations.

The model is currently configured to compute pollutant concentrations from up to five point sources on up to three user-specified receptor grids and at up to ten user-specified individual receptor points. Each receptor grid can contain a maximum of 25 by 25 (625) receptors. Highest and second highest average pollutant concentrations are computed at each receptor for the sum of all sources and the contribution of each source to the sum. The averages are moving averages and up to three

averaging periods can be computed ranging from one hour to 24 hours. The model operates on the whole 500 km by 450 km region or on any sub-region within the domain. The user must specify the sub-region desired at the start of the model run. The decision will be based on the desired resolution of the concentration fields and the amount of input data available.

Hourly, mass-consistent, three-dimensional wind fields, gridded mixing heights, and gridded stabilities are used to drive the model. The flow module currently being used in MELSAR is a three-dimensional, mass-consistent flow model using a terrain-following coordinate system. It was developed by Drake and Huang (1980) and has been described by Drake et al. (1981). Flow channeling around major terrain obstacles under stable atmospheric conditions is treated through consideration of a spatially and temporally dependent Froude number, as described by Whiteman and Allwine (1982). Gridded mixing heights are computed from upper air and surface wind and temperature observations following the technique described by Benkley and Schulman (1979). The gridded stabilities are computed using the method in the model MESOPUFF (Benkley and Bass, 1979). An important feature of the meteorological data processor of MELSAR is that it is configured to receive input data from any location in the domain and the input data do not have to be uniformly spaced in time. The data can come in at any frequency and for any time period of the simulation.

MELSAR is a puff trajectory model in which pollutant concentrations are described in a Gaussian fashion about the puff center of mass, although the distribution is modified by reflections from the ground and inversion surface. Current techniques in puff modeling are used. These include the method proposed by Zannetti (1981) for treating highly non-stationary, inhomogeneous flow conditions such as one would encounter in complex terrain. This method also provides the flexibility for choosing low puff release and sampling rates while simulating a continuous plume. The method is currently configured to operate at a release and sampling rate varying from six puffs per hour to one puff per hour. A release rate of one puff per hour allows an efficient computation for long distance transport while continuing to give adequate plume coverage near the source (less than 10 km, depending on the wind speed).

The dispersion coefficients can be computed in the model using any of three different methods: (1) the formulation in MESOPUFF (Benkley and Bass, 1979); (2) the open country formulation by Briggs (1973); and (3) the method of accounting for terrain enhanced diffusion (MaCready et al., 1974). Spatial and temporal variations in pollutant diffusion as well as the effects of wind shear on diffusion are treated in MELSAR.

This preliminary version of MELSAR consists of four modules named TERRAIN, MET, POLUT, and POLPRC. TERRAIN uses the base terrain file for the region of interest and produces disk files of spatially averaged terrain statistics (e.g., heights, slopes, roughness) for use in the MET and POLUT programs. MET produces hourly winds, gridded mixing heights, and gridded stabilities using upper air and surface winds and temperature observations. POLUT uses the output files from MET and produces pollutant concentrations on a user-specified receptor network for each time step of a simulation. The concentration fields are output to a disk file that is then used by POLPRC for computing moving-average pollutant concentrations for up to three averaging times. The outputs from POLPRC are tables of highest and second highest pollutant concentrations at each receptor. Tables are output for the sum of all sources along with the resulting contribution of each source to the sum. Also, highest and second highest concentration tables are output for each receptor grid and set of individual receptors, considering each source individually.

The principal module yet to be included in MELSAR is the treatment of pollutant transport and diffusion during the period of coupling of valley winds with above-ridgetop winds. The approach will be to release pollution trapped in valley inversions to above ridgetops using the formulation for valley inversion breakup contained in VALMET.

GRAMA FIELD EXPERIMENTS

Two GRAMA field experiments have been conducted in the Green River oil shale region of western Colorado. The first was conducted in a shallow gulch in the Piceance Basin during a ten-day period in August 1980. The data and analyses from this experiment were described by Whiteman et al. (1981) and Laulainen et al. (1981). The second experiment was conducted in cooperation with the U.S. Department of Energy's Atmospheric Studies in Complex Terrain (ASCOT) program during a two-week period in July and August 1982. The GRAMA component of the experiment involved multiple tracer experiments in the deep, well-defined Brush Creek Valley. SF_6 was used to generate an elevated continuous plume, and experiments were designed to determine how SF_6 concentrations would change on the valley floor and sidewalls down-valley from the release site during the post-sunrise temperature inversion breakup period. Analysis of the data from these experiments is continuing and will be reported in future papers. These data will be used to conduct initial evaluations of the VALMET and MELSAR models.

SUMMARY

The model development performed to date in the GRAMA program is leading toward a modeling system with two major components for analyzing the impacts of the oil shale industry with respect to PSD increments over pristine wilderness areas and ambient air quality standards for criteria pollutants. Recognizing that many aspects of complex terrain meteorology and air pollution transport are not well understood, the GRAMA models are being composed in a highly modular fashion so that future upgrading will be simplified. Several of the modules are designed to serve only when site-specific data are not available for direct input.

The first component, VALMET, is an air quality simulation model that predicts concentrations of a nonreactive pollutant arising from an elevated continuous point source located within a well-defined mountain valley. VALMET simulates conditions in which pollutants are carried in locally developed valley circulations that are decoupled from the prevailing regional flow.

The second component, MELSAR, is a mesoscale Lagrangian puff model for predicting pollutant concentrations within a 500 km by 450 km domain encompassing the oil shale development area. MELSAR is to be used principally for estimating short-term SO_2 and TSP average concentrations in determining compliance with PSD regulations. Although a preliminary version of VALMET exists for evaluation, MELSAR is still in the developmental stage. The principal module yet to be included in MELSAR is the treatment of pollutant transport and diffusion during periods of coupling of the regional flow with the valley winds, using the VALMET formulation for valley inversion breakup.

REFERENCES

Benkley, C. W. and A. Bass, 1979: "Development of Mesoscale Air Quality Simulation Models. Volume 3 - User's Guide to MESOPUFF Model". Environmental Research & Technology, Inc., Concord, MA, 124 pp.

Benkley, C. W. and L. L. Schulman, 1979: Estimating Hourly Mixing Depths from Historical Meteorological Data. J. Appl. Meteor., 18, 772-780.

Briggs, G. A., 1973: Diffusion Estimates for Small Emissions. ATDL Contribution File No. 79, Atmospheric Turbulence and Diffusion Laboratory, Oak Ridge, TN.

Drake, R. L. and C. H. Huang, 1980: Mass-Consistent Interpolated Wind Fields for Complex Terrain. Presented at Symposium on Intermediate Range Atmospheric Transport Processes and Technology Assessment, Gatlinburg, TN.

Drake, R. L., C. H. Huang, and W. E. Davis, 1981: "Green River Ambient Model Assessment Program - Progress Report for the Regional and Mesoscale Flow Modeling Components". PNL-3988. Pacific Northwest Laboratory, Richland, WA, 123 pp.

Laulainen, N. S., C. D. Whiteman, W. E. Davis, and J. M. Thorp, 1981: Mixing Layer Growth and Background Air Quality Measurements Over the Colorado Oil Shale Area. Preprints, Second Conference on Mountain Meteorology, American Meteorological Society, Boston, MA, 165-172.

MacCready, P. B., Jr., L. B. Baboolal, and P. B. S. Lissaman, 1974: Diffusion and Turbulence Aloft over Complex Terrain. Presented at AMS Symposium on Atmospheric Diffusion and Air Pollution, Santa Barbara, CA.

Whiteman, C. D. and K. J. Allwine, 1982: "Green River Ambient Model Assessment Program - FY-1982 Progress Report". PNL-4250. Pacific Northwest Laboratory, Richland, WA, 187 pp.

Whiteman, C. D. and K. J. Allwine, 1983a: "VALMET-A Valley Air Pollution Model". PNL-4728. Pacific Northwest Laboratory, Richland, WA, 163 pp.

Whiteman, C. D. and K. J. Allwine, 1983b: Time-Dependent Model of Pollutant Transport and Diffusion in Mountain Valleys. Extended Abstracts, Sixth Symposium on Turbulence and Diffusion, American Meteorological Society, Boston, MA, 173-176.

Whiteman, C. D., N. S. Laulainen, G. A. Sehmel, and J. M. Thorp, 1981: "Green River Air Quality Model Development: Meteorological Data - August 1980 Field Study in the Piceance Creek Basin Oil Shale Resources Area". EPA-600/S7-82-047. EPA, Office of Research and Development, Research Triangle Park, NC. 172 pp.

Whiteman, C. D. and T. B. McKee, 1977: Air Pollution Implications of Inversion Descent in Mountain Valleys. Atmos. Environ., 12, 2151-2158.

Whiteman, C. D. and T. B. McKee, 1982: Breakup of Temperature Inversions in Deep Mountain Valleys: Part II - Thermodynamic Model. J. Appl. Meteor., 21, 290-302.

Zannetti, P., 1981: An Improved Puff Algorithm for Plume Dispersion Simulation. J. Appl. Meteor., 20, 1203-1211.